

FINAL REPORT ON CONTRACT NAS8-35354

SPACE RADIATION STUDIES

07/22/83 - 06/30/89

Submitted by: Cosmic Ray Laboratory

The University of Alabama in Huntsville

Huntsville, Alabama 35899

(NASA-CR-183991) SPACE RADIATION STUDIES
Final Report, 22 Jul. 1983 - 30 Jun. 1989
(Alabama Univ.) 21 p CSCL 038

N90-25925

Unclass

G3/93 0274862

SUMMARY

During this contract two Active Radiation Dosimeters (ARD's) were flown on Spacelab I, performed without fault and were returned to Space Science Laboratory, MSFC for recalibration. During the flight in December 1983, performance was monitored at the Huntsville Operations Center (HOSC). Despite some problems with the Shuttle data system handling the VFI, it could be established that the ARD's were operating normally. Postflight calibrations of both units determined that sensitivities were essentially unchanged from preflight values. Flight tapes have been received for approximately 60% of the flight and it appears that this is the total available. The data has been analyzed in collaboration with Space Science Laboratory, MSFC, and has been published in the open literature.

Also, the Nuclear Radiation Monitor (NRM) was assembled and tested at MSFC. Support was rendered in the areas of materials control and parts were supplied for the supplementary heaters, dome gas-venting device and photomultiplier tube housing. Performance characteristics of some flight-space photomultipliers were measured. The NRM was flown on a balloon-borne test flight and subsequently performed without fault on Spacelab-2 on board the Space Shuttle. This data has also been analyzed and published. Much of the software for the instrument control system, data-handling and data analysis for the NRM was performed under this contract.

In addition, work was performed on passive detectors for the JACEE-7 balloon flight which successfully flew from Alice Springs, Australia to Conception, Paraguay in February 1987.

Post-Flight Calibration of ARD's - 1 and - 2

The instrument (actually #2) is shown in Figure 1. Full details of calibration of these instruments was given in the pre-flight calibration report: Annual Report on Contract NAS8-31170, Calibration of Active Radiation Detector for Spacelab - 1, December 1982, The University of Alabama in Huntsville.

The experimental setup used is shown in Figure 2. Both source and detector are at a fixed distance (~ 1 m) from the floor. The source position was unchanged but the detector and shield were on a movable trolley. The source used was a nominal 100 m Ci of Cs-137 (New England Nuclear NER 401 H, serial number CS-315) of actual activity 93.8 ± 5 m Ci on August 8, 1975. At the time of this calibration, February 1984, its activity was 77.1 m Ci.

The ARD was placed in the γ -field so that the IC and both PC's were equidistant, d meters, from the source. The number of counts per unit time for each detector was recorded. For the PC's the mean of 17 measurements of counts per second was taken in each case. For the ion chamber, the counting interval was varied depending on the count rate so that the uncertainty in counting was less than 3%. At count rate > 50 per 100 s a counting period of 100 s is adequate. At lower count rates longer intervals were used, and at very low rates of a few per 100 s or less, the measurement was made of the intervals between actual counts. This is conveniently done with the GSE since the count register of the ARD is read out and displayed every second by the GSE.

Figure 3 shows the calibration data for both ion chambers after the flight. (circled crosses) The values have been adjusted for the decay of the source. The uncircled crosses and solid lines are the pre-flight calibrations made in January 1983, a little over a year earlier. It may be seen that within experimental error the sensitivities are unchanged. The values of sensitivity were determined to be:

S/N - 1 $6.3 \pm .3$ (6.1) μ rad per count

S/N - 2 $10.3 \pm .4$ (10.4) μ rad per count

Values given in the preflight calibration report are shown in parenthesis.

Figure 4 compares the count-rates of the proportional counters in the two units when placed in β -fields of the same intensity. Two observations are made: All counters respond similarly to these fields at count-rates at least up to several thousand cps, the thresholds on PC-1's in the two units are identical, while the threshold in the PC-2 of S/N - 2 was a little lower causing a 4% difference in count-rate. For anticipated purposes of this data, the difference is immaterial.

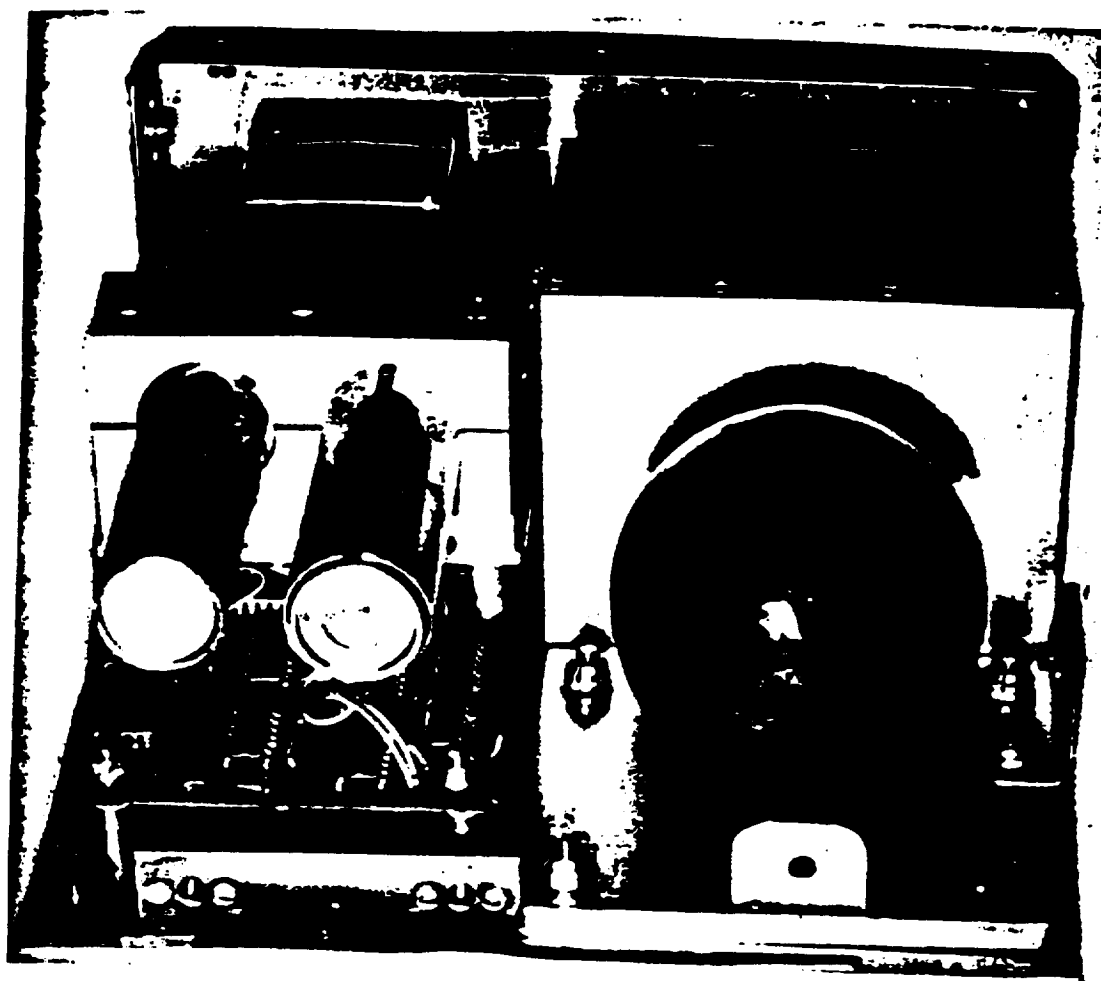
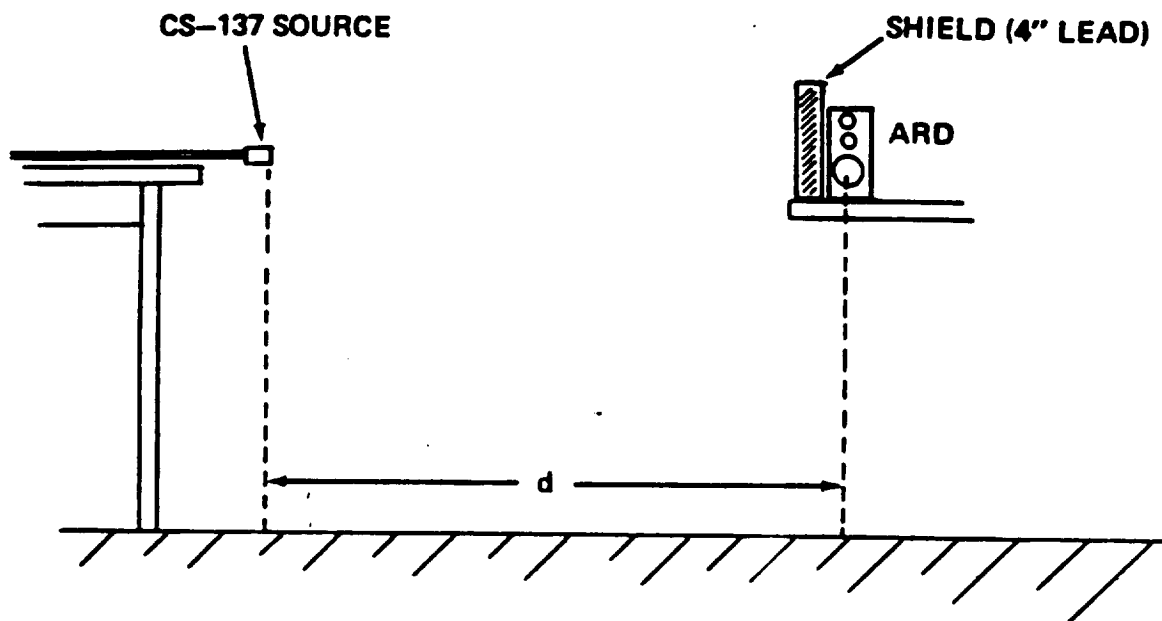


FIGURE 1. ACTIVE RADIATION DETECTOR
(PROTECTIVE COVER REMOVED)

ORIGINAL PAGE IS
OF POOR QUALITY



ARD CALIBRATION
EXPERIMENTAL SETUP: SHADOW SHIELD METHOD

FIGURE 2.

Fig. 3

Linearity Plots for ARDs 1 and 2

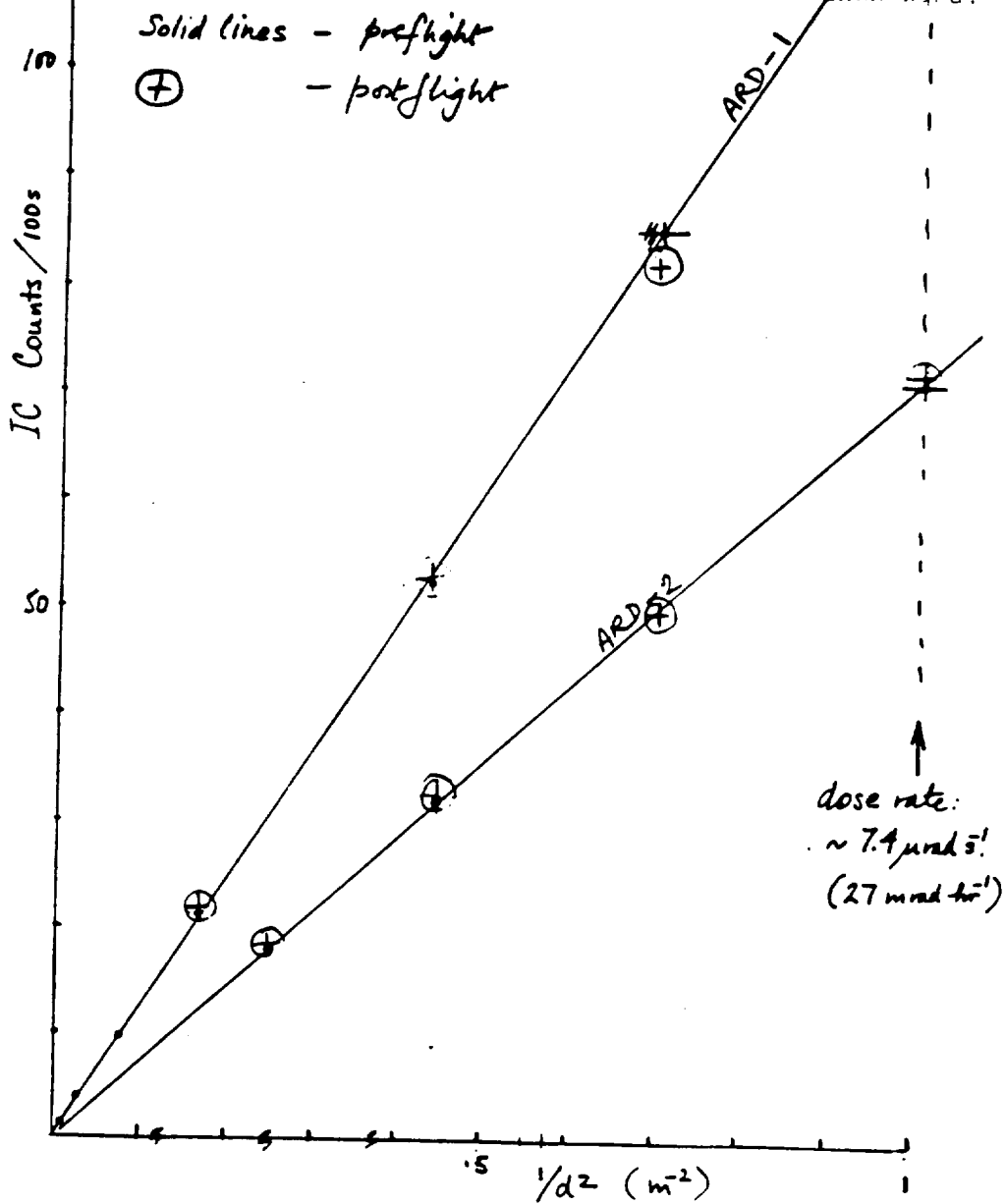
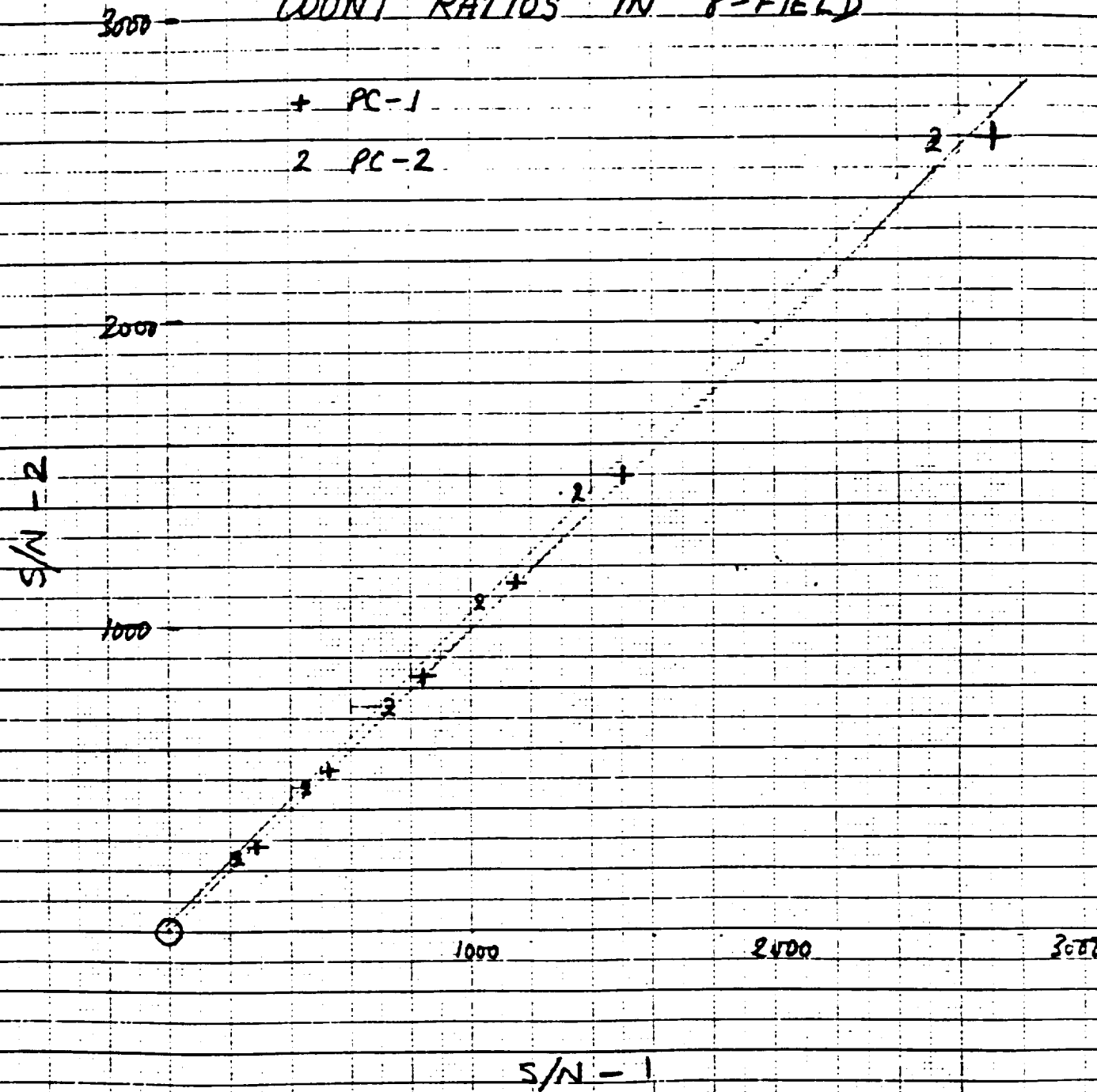


Figure 4

15 Feb 84

COMPARISON OF ARD'S 1 AND 2
PROPORTIONAL COUNTERS:

COUNT RATIOS IN γ -FIELD



It may also be noted that the counters with 1.27 mm copper shield showed rates approximately 10% less than their unshielded counterparts. This is in agreement with calculated absorption loss (8%). The shield would be more effective against soft electrons, should these be encountered.

Figures 5 and 6 show the correspondents between the ion chamber and the PC's (corrected for scattered radiation) after and before the flight respectively. Again, no significant change in behavior is observed.

Photomultiplier Tube Testing

Both the NRM and the Gamma-Ray Observatory will pass through the South Atlantic Anomaly (SAA) periodically. Scintillation crystals produce a high intensity flight under these conditions, and it is important to know the time-response of recovery of the PMT's and whether any permanent effect is obtained. Tests were performed on EMI-D611 tubes which are equivalent to EMI-9791 except the dynodes are of BeCu instead of being coated with CsSb.

Light Cone Apparatus:

The tubes were balanced on the light cone at flight gains which required high voltage settings that were from 50 to 120 volts below test ticket 50A/lumen voltages. Then the three PMTs were exposed to a bright Am241 source which has a peak at 60KeV. The resulting gain change at a count rate of 417kHz was 1.6% and a change of 9.3% at 1029kHz (compared with a 9791 mounted on a 5 x 5 crystal that changed 2.5% at a rate of 488kHz).

Measurements were also taken (at flight gains) to determine the charge deposited by a Na22 511KeV line (8.3pC). Using a calculated incident flux of 1×10^{-5} MeV/sec average charged-particle energy deposition in a 350km orbit SAA exposure, an expected anode current of 1.6uA was calculated.

Figure 5

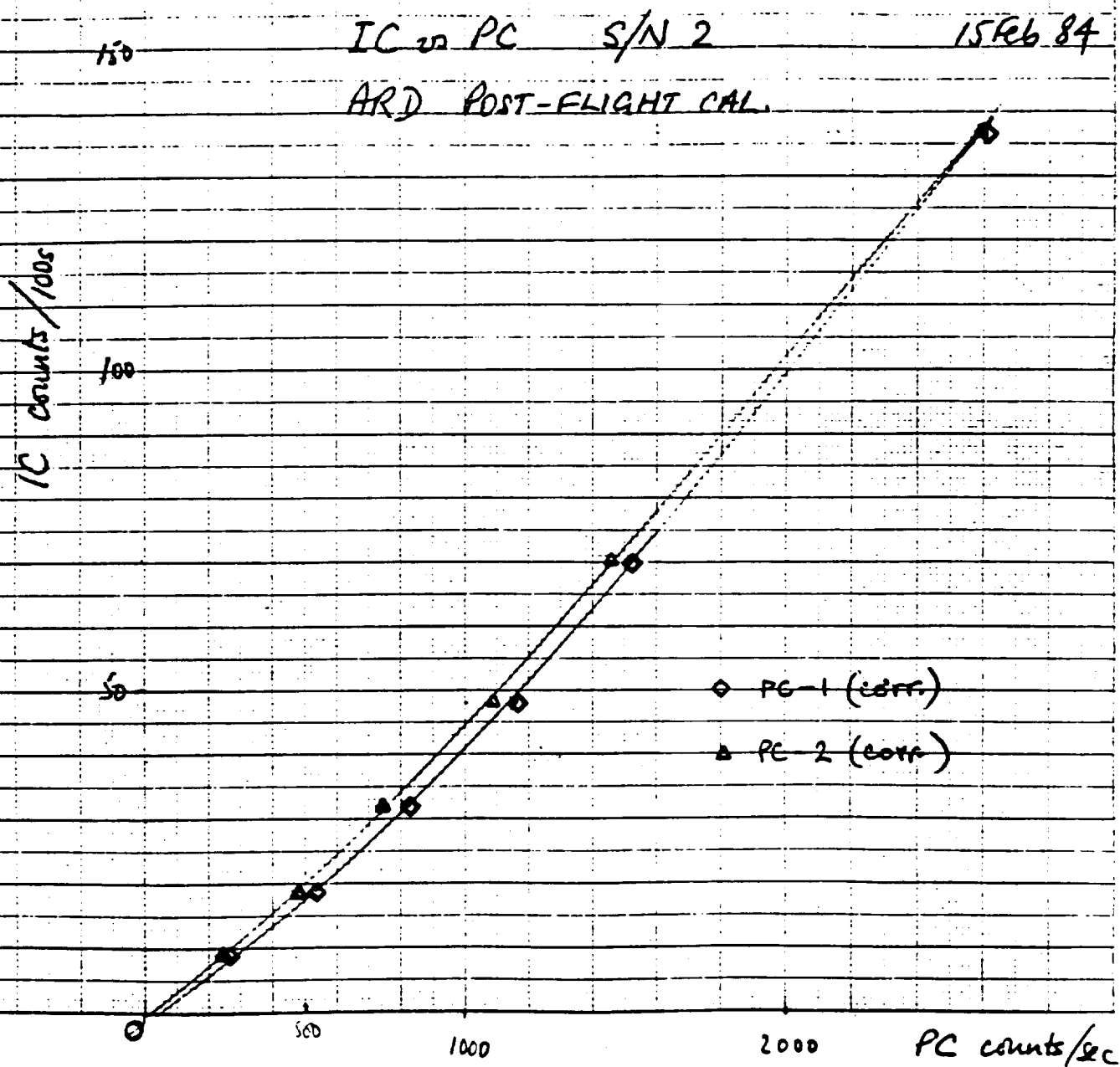
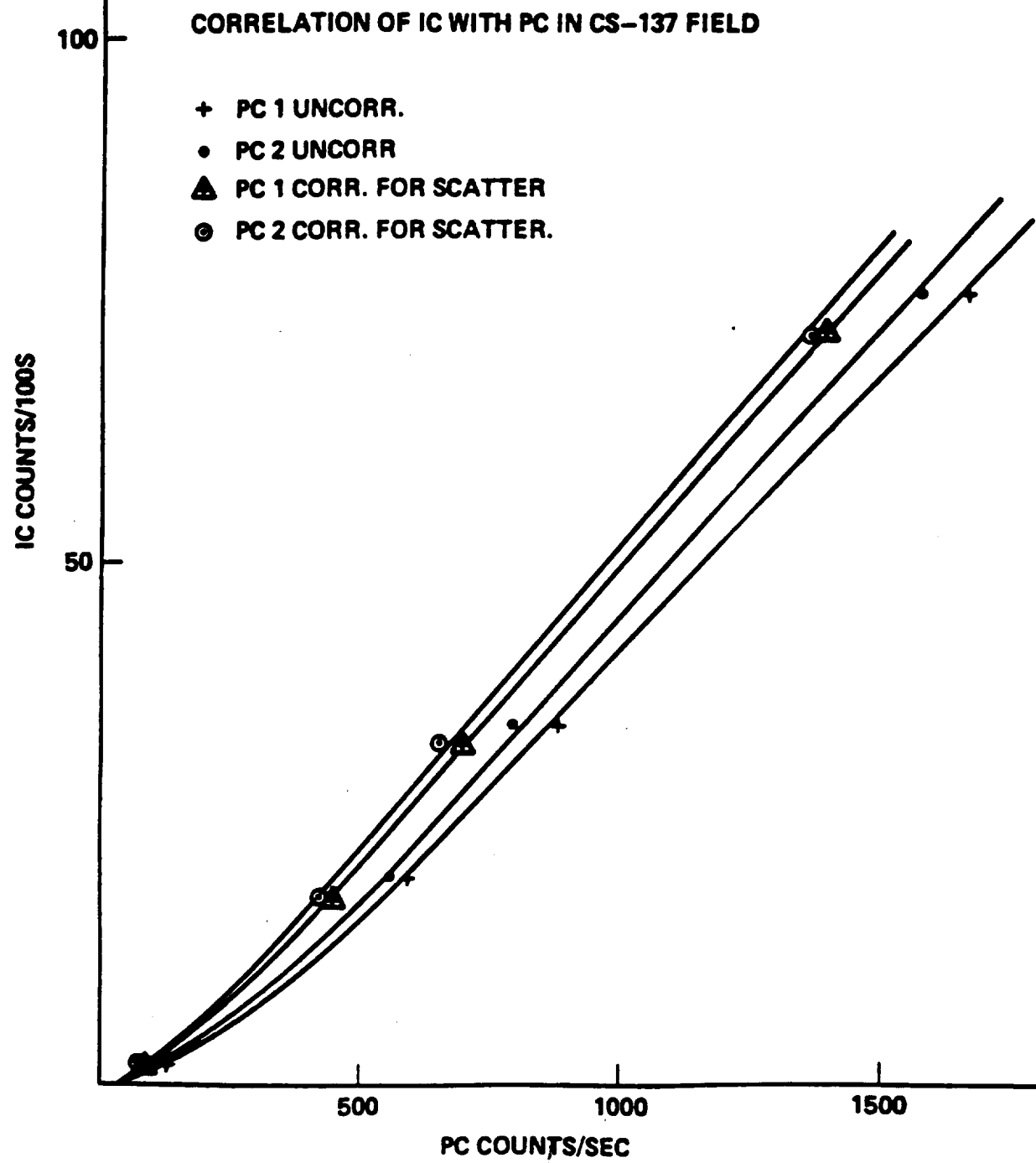


FIG. 6 ARD NO. 2



Measurements in PMTBOX:

In this box two things were studied: gain recovery after simulated SAA exposure and gain stability on periods of 12 hours.

The calculated SAA equivalent of 1.6uA produced no measurable gain change whether the high voltage was on or off. However, the original incident flux from which the current of 1.6uA was calculated, was deemed too low. Therefore, the rest of the SAA simulations were made at a higher light levels and correspondingly higher anode currents. Gain of the BeCu changed no more than one percent after a SAA with mean current 13uA with the High Voltage off during the SAA exposure. The worst case gain recovery was 5 minutes. In comparison the 9791's, had a gain change significantly less than one percent but the gain did still change slightly. Recovery from this slight gain change was almost instantaneous. The difference in behavior of the two types of tubes became more pronounced when the high voltage was left on during the simulated SAA (13uA). The BeCe tubes showed gain increases of 7% (as opposed to the 9791 which showed a 3% gain decrease). Both tubes showed slow gain recovery after SAA exposures during which the high voltage was on. Worst case for the BeCu type tubes was, after three hours, a gain recovery of only 30% of the gain change. The only CsSb type tube observed, recovered 50% of the gain change after three hours.

The BeCu tubes showed stability (less than 1% gain change) over periods of twelve hours when the room temperature stayed constant (no fluctuation in temperature greater than 1/2 of a degree Celsius for the same 12 hours). When the temperature fluctuated 1 degree, the gain changed 2 percent for one tube and 4% for the other tube. This is not necessarily due to the tube as none of the other electronics were in a temperature controlled environment.

Conclusion:

Based on a sample of three BeCu tubes, there is no reason they could not be used in lieu of the 9791's. The slow recovery after SAA exposure is the only drawback seen, but this should not be a problem as long as the high voltage is turned off during SAA.

COSPAR 1986 Paper XII.2.7
Toulouse, France
PREPRINT

Appeared in "Advances in Space Research, Vol.7, No.5, pp(5)231-234,(1987).

Measurements of Background Gamma Radiation on Spacelab 2

G.J. Fishman
Space Science Laboratory
NASA Marshall Space Flight Center
Huntsville, AL 35812 USA

W.S. Paciasas
J.C. Gregory
University of Alabama in Huntsville
Huntsville, AL 35812 USA

Abstract

A Nuclear Radiation Monitor (NRM) was flown as part of the verification instrumentation on the Spacelab 2 mission, July 29 - August 6, 1985. The monitor is a 12.7 cm diameter, 12.7 cm thick NaI(Tl) scintillation detector surrounded by a charged particle detector. The NRM, mounted on a pedestal near the rear of the payload bay, has a nearly omnidirectional response. Gamma rays are detected with high efficiency over the energy range 0.06 to 30 MeV. The monitor operated throughout most of the mission, recording spectra every 20 seconds and counting rates in coarse energy bands on finer timescales.

The gamma radiation environment on Spacelab consists of cosmic-ray and trapped proton secondary radiation in the Spacelab/Shuttle, Earth albedo radiation, and delayed induced radioactivity in the detector and surrounding materials. Passages through the South Atlantic anomaly protons produce a well-defined background enhancement. Episodes of greatly increased background due to trapped electrons are seen on many passes through high latitudes. This background has a soft spectrum, characteristic of bremsstrahlung radiation. These enhancements often have complex temporal structure.

INTRODUCTION

Many experiments on future Shuttle missions and other low-Earth orbit missions are sensitive to the ambient radiation environment. The Nuclear Radiation Monitor (NRM) was designed to measure various components of this environment on an early Shuttle/Spacelab mission. The primary objective of the instrument was to monitor the omnidirectional gamma-ray, proton, electron, and neutron fluxes over a wide energy range in the payload bay. These measurements are made in conjunction with a more comprehensive, multi-faceted program to characterize the Shuttle/Spacelab radiation fluxes and dosages (Parnell et al., 1986). Data from the NRM will be made available to experimenters for the analysis and interpretation of their data and for the design of future Spacelab experiments.

EXPERIMENT

The Nuclear Radiation Monitor (NRM) was flown in the payload bay of the Space Shuttle Challenger from July 29 to August 6, 1985, as part of the Spacelab 2 verification flight instrumentation. It operated continuously during the orbital portion of the flight. The Spacelab 2 mission had an orbital inclination of 49.5° and an altitude which varied between 290 km and 327 km during the flight.

The primary elements of the NRM detector assembly are shown in Figure 1. The NRM central detector is a 12.7 cm diameter, 12.7 cm

thick NaI(Tl) scintillation crystal coupled to a 12.7 cm diameter PMT. The energy resolution was 9.0% at 662 keV. A plastic scintillator, 1 cm thick surrounded the side and one end of the scintillator crystal. Its scintillation light was collected by three 5 cm diameter PMT's. The inner surface of the NRM's dome-shaped housing was coated with reflective white paint to enable more efficient light collection from the plastic shield. The detector has a nearly omnidirectional response. Passive materials covering the detector crystal and other components of the NRM limited the low energy response of the detector to about 80 keV, although the electronic threshold was set at 60 keV. The detector was mounted on a pedestal on pallet no. 3, approximately 1 meter above and 1 meter inside the payload bay sill. There were no massive objects within ~2 meters; the detector had a representative "view" of the inside of the payload bay.

Pulses from the central crystal are processed simultaneously in two ways using: (1) a fast sixteen channel encoder/scaler with negligible dead-time, and (2) a peak-sensing ADC system which produces higher resolution spectra but with a fixed deadtime of 106 microseconds per pulse and less time resolution. The sixteen channels of encoder/scalers are allocated as follows: (1) twelve logarithmically spaced channels with threshold energies from 60 keV to 30 MeV, from pulses in the NaI crystal, not in coincidence with a pulse in the plastic scintillator, (2) three channels with thresholds at 60 keV, 2.8 MeV, and 30 MeV in coincidence with a

pulse in the plastic scintillator, and (3) one channel represents the rate of pulses in the plastic scintillator, above a threshold of approximately 800 keV. Counts in these sixteen channels are accumulated in 8-bit scalars and read out every 5.25 ms. There are data gaps of 2.016 s duration every 20.16 s due to limitations of the data system.

A total of six spectra are accumulated for 18.144 s and read out every 20.160 s. Spectra of three different dispersions are accumulated from the central detector in coincidence with pulses from the plastic detector and three in anticoincidence with the plastic detector. The approximate dispersions are 1.5, 15, and 150 keV/channel in each spectrum of 510 channels.

The data system for the NRM represented the first use of the Spacelab Payload Standardized Modular Electronics (SPSME) components. These modules are CAMAC-compatible, space qualified electronics that can be configured and programmed for a variety of experiments and include appropriate interfaces to the Spacelab command, data, and power systems. The SPSME modules utilized for the NRM included a high rate multiplexer interface, a remote acquisition unit interface, a programmable crate controller, a time interface module, an auxiliary memory module, an ADC module, and a power supply module. The total data rate from the NRM/SPSME was 24.381 kbps.

PRELIMINARY RESULTS

A portion of the data containing a strong gamma ray burst has been analyzed in some detail and the results are reported elsewhere (Fishman et al., 1986). Analysis of the remaining data has been oriented toward development of a comprehensive time history and spectral data base for the entire mission. The gamma ray and charged particle counting rates were integrated to produce a data base with a minimum time resolution of 0.504 s. The spectral data base retains the inherent minimum time resolution of 20.16 s.

Figure 2 is an example of the available rate histories. Two different gamma-ray channels are plotted along with the integral rate of events in the central detector in coincidence with the plastic detector. The minimum value of the gamma ray rate in the 100 - 600 keV range is about 6 photon/cm²-s. The charged particle rate above 800 keV in the plastic shield has a minimum value of about 1 particle/cm²-s. The characteristic sinusoidal modulation of the background results from the orbital position dependence of the cosmic ray secondary production in the atmosphere and the spacecraft. The peak-to-peak amplitude of this component in gamma rays is typically a factor of two or three for the 50° orbital inclination.

Significant increases over the basic orbital modulation can also be seen in Figure 2. At least two processes are responsible for this. In one case, passages through the South Atlantic Anomaly (SAA) region produce intense events which have a hard spectrum,

smooth time structure, and last up to ~15 minutes. As can be seen from their location with respect to the sinusoidal variations, these passages can occur at relatively low geomagnetic latitude. Activation of the detector following the SAA passages is not readily apparent in these plots, due probably to the dominance of continuum emission over line emission in a detector with omnidirectional response.

The remaining enhancements in Figure 2 represent background variations due to trapped electrons. These are only seen at high latitudes and have relatively soft spectra, as they are not prominent in the higher energy gamma ray channel. The gamma rays represent bremsstrahlung from the electron interactions in the atmosphere and the spacecraft. For the events in Figure 2, the electrons are not detected directly in the charged particle rate, probably due to the spacecraft orientation, since in other cases the charged particle rate has been seen to increase in coincidence with the soft-spectrum gamma ray rate increases.

Another feature of the electron events is the frequent occurrence of variations on timescales as short as 1 s, much faster than the proton events. Figure 3 shows one of these events with finer time resolution in the 100 - 600 keV gamma ray range. A rapid oscillation is seen in a portion of these data. Precipitation of energetic electrons at high latitudes with rapid, complex time structure has been observed and interpreted previously (cf. Barcus, Brown, and Rosenberg, 1966; Thorne and Kennel, 1971; Imhof et al.,

1977; West and Parks, 1984; Imhof et al., 1986.).

Figure 4 shows a typical raw spectrum at the time of an electron event compared with a spectrum taken at a background minimum. The bremsstrahlung spectrum is relatively soft, the e-folding energy of the excess being ~100 keV. In contrast, the gamma-ray spectra of SAA passages typically differ from the low background regions in intensity but not in spectral shape. The spectral distinction of proton enhancements shows up primarily in the highest-energy charged particle spectra.

SUMMARY

The NRM measured background gamma rays and charged particles nearly continuously during the Spacelab 2 mission. Preliminary investigation of the spectra and time histories shows a variety of expected effects resulting from incident charged particles, Earth albedo radiation, and secondary radiation produced within the vehicle itself. While the first two of these are well known from previous experiments, the latter component is unique to the Shuttle/Spacelab system and represents a large fraction of the total. Work is currently underway to characterize the secondary radiation in a manner which will be useful in the design of future Spacelab experiments.

References

Barcus, J.R., R.R. Brown, and T.J. Rosenberg, "Spatial and Temporal Character of Fast Variations in Auroral-Zone X-rays", J. Geophys. Res., 71, 125 (1966).

Fishman, G.J., "The Nuclear Radiation Monitor for the Spacelab/Shuttle", in Gamma Ray Spectroscopy in Astrophysics, NASA TM-79619, p479 (1978).

Fishman, G.J., W.S. Paciesas, C.A. Meegan, and R.B. Wilson, "Observation of a Strong Gamma Ray Burst on the Spacelab 2 Mission" (these proceedings) COSPAR Paper E.4.1.4 (1986).

Imhof, W.F., H.D. Voss, J.B. Reagan, D.W. Datlowe, E.E. Gaines, J. Mobilia, and D.S. Evans, "Relativistic Electron and Energetic Ion Precipitation Spikes Near the Plasmapause", J. Geophys. Res., 91, 3077 (1986).

Imhof, W.L., J.B. Reagan, G.H. Nakano, and E.E. Gaines, "Narrow Spikes in the Selective Precipitation of Relativistic Electrons at Mid-Latitudes", J. Geophys. Res., 82, 117 (1977).

Parnell, T.A., J.W. Watts, G.J. Fishman, E.V. Benton, A.L. Frank, and J.E. Gregory, "The Measured Radiation Environment within Spacelabs 1 and 2 and Comparison with Predictions", (these proceedings) COSPAR Paper F.1.1.4 (1986).

Thorne, R.M. and Kennel, C.F., "Relativistic Electron precipitation during Magnetic Storm Main Phase", J. Geophys. Res., 76, 4446 (1971).

West, R.H. and G.K. Parks, "ELF Emission and Relativistic Electron Precipitation", J. Geophys. Res., 89, 159 (1984).

Figure Captions

- Fig. 1** **The Nuclear Radiation Detector (NRM) on Spacelab 2. The primary detector components are indicated.**
- Fig. 2** **Approximately 7.5 orbits of background data during the Spacelab 2 mission. Shown are the detected count rates in two gamma-ray energy regions and the integral counting rate from the scintillation detector in coincidence with the plastic scintillator. Several regions of increased background due to trapped electrons (E) and protons (SAA) are indicated, superimposed on the underlying modulation due to geomagnetic latitude variations. The time resolution of the data is 20.16 s.**
- Fig. 3** **The low energy gamma ray counting rate during the time of an enhanced, variable electron background. The time resolution is 0.504 s.**
- Fig. 4** **Spectrum of low energy gamma rays during an electron enhancement compared with a normal background spectrum. The energy scale is approximately 1.5 keV/chan.**